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CLUES TO GALAXY ACTIVITY FROM RICH CLUSTER SIMULATIONS

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ABSTRACT. New simulations of rich cluster evolution are used to evaluate the "first infall" hypothesis of Gunn and Dressler — the idea that the enhanced fraction of active galaxies seen in high redshift clusters is due to a one-time burst of star formation triggered by the rapid rise in external pressure as a galaxy plows into the hot intracluster medium (ICM). Using three-dimensional simulations which contain both baryonic gas and collisionless dark material, local static pressure histories for test orbits of galaxies are generated and a simple trigger threshold based on $dP/dt|_{P_{ISM}}$ is applied to define an "active" fraction of the population. The results lend qualitative and quantitative support to the first infall interpretation.

dP/dt/P sub ism

1. Motivation

Spectroscopic observations of galaxies in clusters at high redshift by Dressler and Gunn (1982; 1983; Dressler 1987; Gunn 1989) have revealed that the fraction of active galaxies in rich clusters increases with look-back time from values $\lesssim 5\%$ at the present to $\sim 30\%$ at $z \sim 0.5-0.8$. The active population includes Type I Seyferts, high excitation narrow-line emission systems and "post-starburst" galaxies designated E+A because their spectra are consistent with that expected from a superposition of an old stellar population with main sequence A stars formed during a significant burst occuring $\sim 10^9$ yr earlier (Dressler and Gunn 1983). The active galaxies are concentrated within the inner ~ 500 kpc of the cluster but appear somewhat less centrally concentrated than the passive population. The line-of-sight velocity dispersion of the active galaxies is typically $\sim 70\%$ larger than that of the passive population.

Gunn and Dressler suggest an infall model for these observations in which starbursts are triggered by gas-rich galaxies' first infall into the highly pressurized cluster ICM. A pressure sensive trigger is assumed to initiate the burst. As the galaxy falls into the cluster, the tenuous, hot phase of its interstellar medium (ISM) will be ram-pressure stripped while higher density, cold clouds remain bound within the galactic potential. Since pressures $30 - 300$ times the conventional pressure in the cool phase of the Milky Way $P_{ISM} \simeq 10^{3.5}$ K cm^{-3} are typical at the centers of rich clusters, the remaining gas in the infalling galaxy will be compressed as it climbs the rising pressure profile toward the center of the cluster. If the compression is rapid and the galaxy sufficiently gas-rich, then a significant starburst may be produced.

Recent numerical simulations (Evrard 1989) which follow the evolution of a gravitationally coupled system of collisionless particles and collisional gas allow gross details of this scenario to be examined experimentally. The simulations follow the dynamics within a $50\,h_{50}^{-1}$ Mpc periodic cube whose initial density field is constrained to produce a rich cluster in a Hubble time (Bertschinger 1987). One Coma-richness cluster will be examined here. A cold dark matter initial spectrum with $\Omega = 1$, $H_o = 50\,h_{50}$ km s^{-1} Mpc^{-1}, $\Omega_{ICM} = 0.1$ and a spectrum normalization $\sigma(16\,h_{50}^{-1}$ Mpc$) \equiv b^{-1} = 0.6$ is assumed. Two sets of 4096 particles are used to represent the dynamically distinct components. Gravity is calculated using the P3M technique and the 3-D gas dynamics is followed with Smoothed Particle Hydrodynamics (SPH) — the method is described in Evrard (1988). The evolution is followed from $z = 7$ to the present and the simulations can

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resolve structure down to $\sim 200\,h_{50}^{-1}$ kpc. The origin of the ICM is assumed primordial — mass and energy input from galaxies is ignored. The thermal history of the ICM is thus determined by shock heating (and susequent adiabatic evolution) of mildly supersonic, clumpy gas infalling into a hierarchically evolving potential well of dominant collisionless matter.

2. Results

The collisionless particles in the simulation are used to define test orbits for galaxies within the cluster potential. Local pressure histories $P(t)$ for a random selection of orbits are determined by interpolating the pressures of the nearby gas particle population. An "active" fraction is defined by those orbits which have undergone a rapid rise in pressure above the interstellar value $P_{ISM} = 10^{3.5}$ K cm^{-3} in the last 10^9 yr. Specifcally, the rise must be greater than a factor 5 in an interval less than $\Delta t = 0.36 \times 10^9$ yr (2 simulation output intervals). Only one burst per orbit is allowed.

Figure 1 shows the pressure histories of 30 orbits randomly drawn from within an Abell radius $R_A = 3\,h_{50}^{-1}$ Mpc at both high ($z = 0.59$, $t_9 = 6.6$) and low ($z = 0.07$, $t_9 = 12.0$) redshifts. The cluster viewed at high z has a larger fraction of infalling orbits satisfying the active criteria. The fraction of active orbits using all (between 500 and 1000) collisionless orbits within an Abell radius at redshift z is shown in Figure 2. The fraction drops from roughly 20% at high z to $\lesssim 5\%$ for redshifts $z \lesssim 0.3$. A merger event creates the bump at $z = 0.1$.

Histograms of projected radii and velocities (relative to the known 3-D center-of-mass of the cluster) formed from a composite of 90 orbits compiled at high and low redshift are shown in Figures 3 and 4. The active orbits lie preferentially in the inner $1\,h_{50}^{-1}$ Mpc at high z, extending out to $\sim 2\,h_{50}^{-1}$ Mpc at low redshift. The histogram of line-of-sight velocities shows that the active fraction populates a high velocity subset of all orbits. The flatter and broader (by $\sim$ 70%) dispersion of the active sample agrees quantitatively with the observed redshift behavior of active galaxies in distant clusters (see Fig. 4 of Dressler 1987).

3. Summary

Numerical simulations of clusters including a gas dynamic ICM support the interpretation that the larger fraction of active galaxies seen in clusters at high redshift arises from galaxy-ICM interactions. A simple activity criterion based on a rapid static pressure increase was successful in reproducing several properties of the observed active cluster population : 1) a large drop in activity over the past $\sim$ 5 billion years, 2) the central concentration of active galaxies and 3) their broader and flatter velocity distribution. It remains to be understood what is the "micro-physics" driving the starburst in this complex galaxy-ICM interaction.

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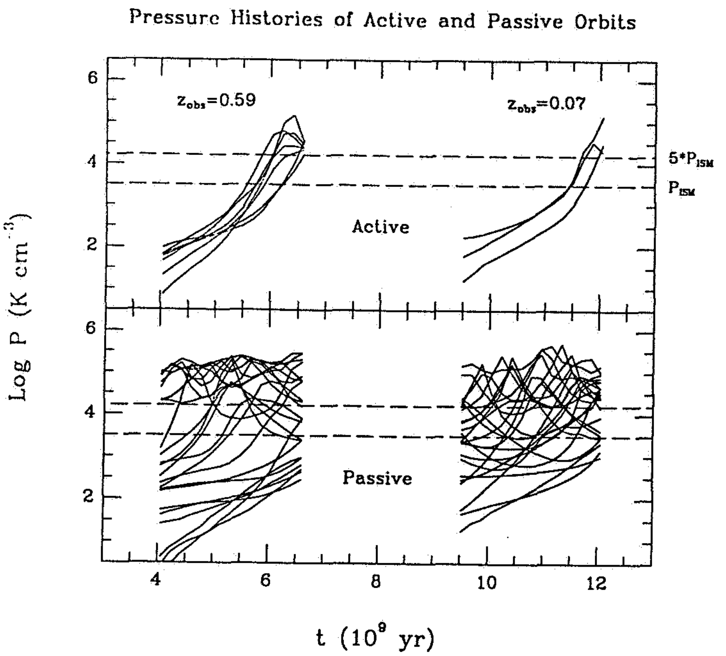

Fig. 1

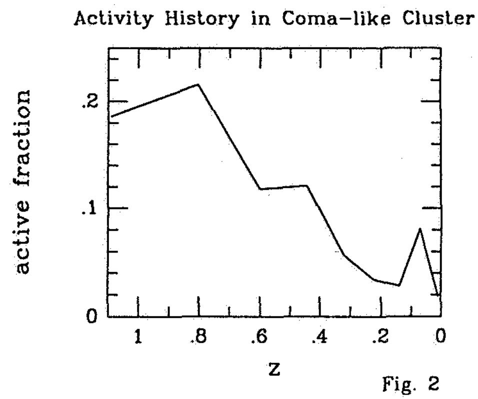

Fig. 2

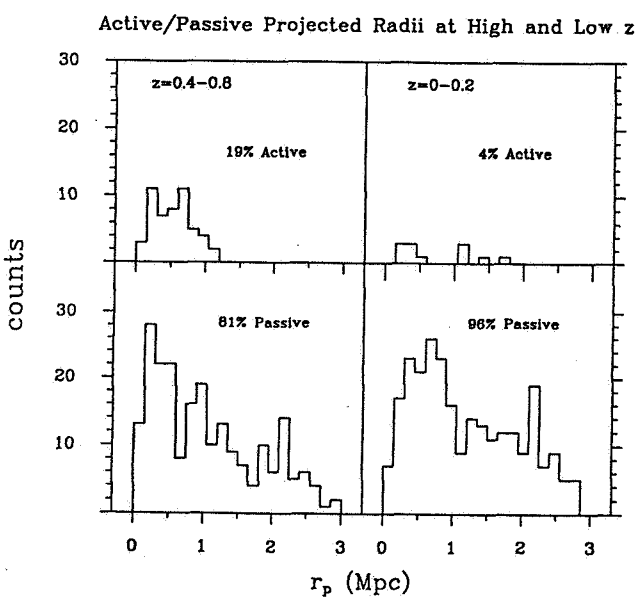

Fig. 3

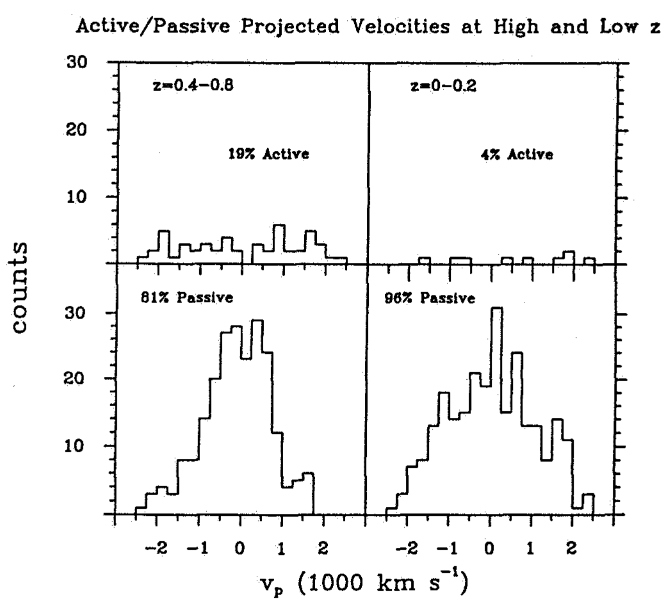

Fig. 4